

# An Investigation of Collisions between Fiber Positioning Units in LAMOST

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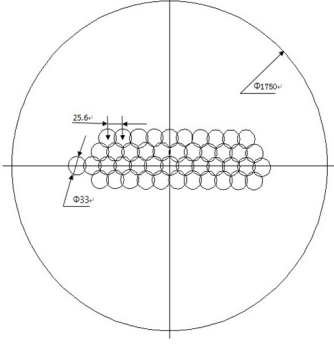
**Abstract** The arrangement of the fiber positioning units in LAMOST focal plane may lead to the collisions during the fiber allocation. To avoid these collisions, the soft protection system has to abandon some targets located in the overlapped field of the adjacent fiber units. In this paper, we firstly analyzed the probability of the collisions between fibers and inferred their possible reasons. It is useful to solve the problem of the fiber-positioning units collisions so as to improve LAMOST efficiency. Based on it, a collision handling system is designed by using the master-slave control structure between the micro control unit (MCU) and the microcomputer. The simulated experiments validate that the system can provide real-time inspection and swap the information between the fiber unit controllers and the main controller.

**Key words:** methods: statistical, telescopes, instrumentation: detectors, methods: data analysis, methods: observational

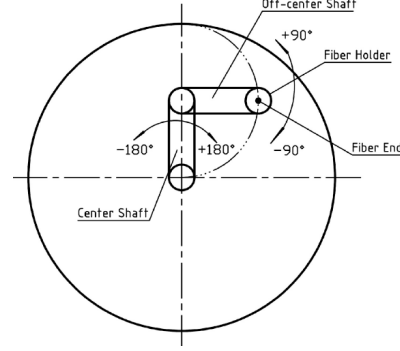
## 1 INTRODUCTION

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), which is also called the Guo Shou Jing Telescope, is a special reflecting Schmidt telescope with large aperture and wide field of view. The available large focal surface accommodates up to 4000 fibers, by which the collected light of distant and faint celestial objects down to 20.5 magnitudes is fed into the spectrographs, promising a very high spectrum acquiring rate of several ten-thousands of spectra per night (Cui et al., 2012; Chen et al., 2014).

The focal surface of the telescope, which has a diameter of 1.75 m, is divided into 4,000 individual domains as shown in Fig. 1. The diameter of each fiber is 33 mm and the distance between two adjacent units is 25.6 mm, so the overlapped domain will appear in the observation field of every two adjacent fiber units (Cui et al., 2012). Therefore, the fiber arrangement can efficiently avoid the blind areas of FoVs. At the same time, the positioning procedure of the relevant fiber units may also be confused when the targets allocate in the overlapped field. On the other hand, each unit is driven by two stepping motors (Xing



**Fig. 1** The distribution of fiber-positioning units in the focal plate (Cui et al., 2012).



**Fig. 2** Double revolving fiber-positioning unit (Cui et al., 2012).

around its fixed end in a range of  $\pm 180^\circ$ , and an off-center shaft which revolves around its end that is connected to the free end of the central shaft in arrange of  $\pm 90^\circ$  (Li et al., 2000). Theoretically speaking, mechanical collisions among the fiber positioning units must be avoided by the Survey Strategy System (SSS) of LAMOST which would abandon several objects.

In this study, we firstly analyzed the probability of the collisions among fibers by utilizing binomial probability distribution. And then, we inferred several relevant reasons for the losing targets during the observation. Based on it, a collision handling system is designed by using the master-slave control structure between the micro control unit (MCU) and the microcomputer. In order to validate its usefulness and correctness, the simulated experiments are designed and used for seven fiber positioning units neighbors.

This paper is organized as follows. In Sec. 2, we analyze the collision probability in the overlapped area of the fiber units. Additionally, we explore the possible reasons for losing objects during the survey. The designation of hardware collision handling system is detailed in Sec. 3. The results and discussions are summarized in Sec. 4.

## 2 MECHANICAL COLLISIONS BETWEEN FIBER POSITIONING UNITS

### 2.1 The Fiber Allocation Rate

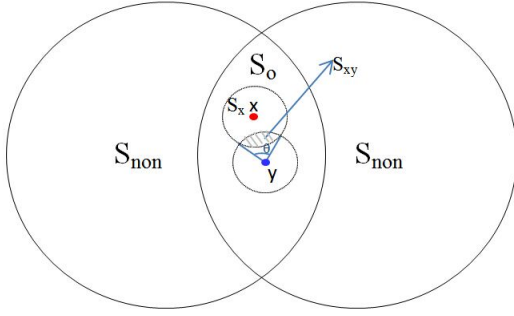
In a multi-fiber and dense distribution system, the allocation rate of the fibers should be taken into account. Assuming that the distribution of objects in the focal surface of LAMOST is uniform, the probability ( $p$ ) of a object in a certain domain equals to the area ratio of the domain and the entire focal surface (Peng et al., 2003). The probability of the objects distribution follows the binomial distribution which is shown in Eq. 1.

$$p(K, N) = C_N^K p^K (1 - p)^{(N-K)}, \quad (1)$$

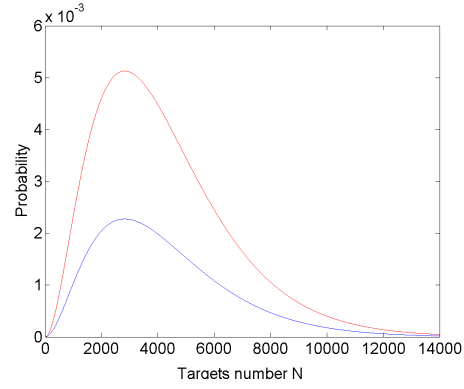
where  $N$  is the number of objects in the FoV, and  $K$  is the number of objects in a domain.

#### 2.1.1 The Collision Probability of Two Objects in a Overlapped Area

Assuming that any pair of adjacent units is independent from the others, and each fiber unit has six neighbors, we estimate that about 11630 pairs of units are in the LAMOST fiber plate. A mechanical collision may happen in the overlapped region ( $S_o$ ) as shown in Fig. 3, since the fiber could not aim at the targets



**Fig. 3** Divided domains in a pair of fiber units. In this figure,  $S_o$  represents the overlapped region,  $S_{non}$  is the non-overlapped area,  $x$  and  $y$  are two targets, and  $S_x$  is a circle area defined by the center  $x$  and the radius  $4.5 \text{ mm}$ .



**Fig. 4** The collision probability  $p$  changes with  $N$  (the number of objects). The red curve is the variation tendency of  $p$  when the radius of  $S_x$  is  $6 \text{ mm}$  and the blue curve of which is  $4.5 \text{ mm}$ .

which center is  $x$  and radius is  $4.5 \text{ mm}$ , the collision will occur when target  $y$  falls in  $S_x$ . Thus, the collision probability of two objects in a overlapped area obeys the binomial distribution described as Eq. 2.

$$p = C_N^2 p_{S_o}^2 (1 - p_{S_o})^{N-2} (1 - p_{S_{non}})^N p_{S_x}, \quad (2)$$

where  $C_N^2 p_{S_o}^2 (1 - p_{S_o})^{N-2}$  is the probability of only two objects in the overlapped region  $S_o$ ,  $C_N^0 (1 - p_{S_{non}})^N$  is the probability of no objects in  $S_{non}$ , and  $p_{S_x}$  is the probability of the two objects allocated in  $S_x$  simultaneously. We calculate this probability for different amount of targets listed in Table 1

The probability curve for the collision of the two objects is the  $p$  vs.  $N$  (various objects number) as plotted in Fig. 4. The red curve represents  $p$  changes along with  $N$  when the radius of  $S_x$  is  $6 \text{ mm}$  and the blue curve of which is  $4.5 \text{ mm}$ .  $4.5 \text{ mm}$  is just the theoretical radius of  $S_x$ , yet the radius is slightly larger than the theoretical one in practice. So we also considered  $6 \text{ mm}$  as the radius of  $S_x$  in the probability calculation, which would be a more reasonable value. In the curve shown in Fig. 4, we see that the collision probability  $p$  reaches a peak at the number about 3,500, which is close to the desirable number of targets (except for a few of skylight fiber units) in each observation. It is necessary to handle these collisions.

### 2.1.2 The Collision Probability of More Objects in a Overlapped Area

The collision probability caused by more than two objects allocated in the collision areas is relatively small. In the case of only three objects in  $S_o$ , the collision probability is defined as Eq. 3 and its value is shown in Table 1.

$$p = C_N^3 p_{S_o}^3 (1 - p_{S_o})^{N-3} (1 - p_{S_{non}})^N p_{S_{xy}}, \quad (3)$$

where  $S_{xy}$  is the domain that defined by two objects  $x$  and  $y$ , which is described as Eq. 4 and the shadow part of Fig. 3.

$$S_{xy} = \frac{\int_0^{4.5} \frac{2[\frac{\theta \pi r^2}{2\pi} - (r/2) \sin(\theta/2)] 2\pi l}{S_o} dl}{S_o}. \quad (4)$$

**Table 1** The Number of Lost Objects.

N	2500		3500		6000		8000		10000		14000	
	4.5 mm	6 mm	4.5 mm	6 mm	4.5 mm	6 mm	4.5 mm	6 mm	4.5 mm	6 mm	4.5 mm	6 mm
$p_{S_x}/n_{S_x}$	0.0022	0.005	0.0022	0.0049	0.0011	0.0024	0.0005	0.0011	0.0002	0.0004	0.0	0.0
	27	61	26	58	13	29	6	13	2	5	0	0
$p_{S_{xy}}/n_{S_{xy}}$	0	0.0001	0.0001	0.0002	0.0001	0.0002	0.0	0.0	0.0	0.0	0.0	0.0
	0	6	8	14	12	24	0	0	0	0	0	0
$\Sigma(n_{S_x}, n_{S_{xy}})$	27	67	34	62	25	53	6	13	2	5	0	0

NOTES:

1.  $N$  means the input catalogue. 4.5 mm is the theoretical minimal radius and 6 mm is the more reasonable value in calculation of the collision probability.
2.  $p_{S_x}/n_{S_x}$  is the collision probability of the only two objects in the overlapped domain and the losing targets number respectively.  $p_{S_{xy}}/n_{S_{xy}}$  is the ones of the only three objects in the overlapped domain and the losing targets number.
3. The probability of more than three targets in the overlapped domain in LAMOST is close to zero, so we don't list them in this table.
4.  $\Sigma(n_2, n_3)$  is the total number of losing targets of  $n_2$  and  $n_3$ .

**Table 2** Examples of Survey Strategies from LAMOST General Survey, where  $M$  Represents the Number of Allocating Catalogue.

Plate	Time	M	Observed Objects	Miss Objects	Failed Rate
GAC100N17B1	2014-12-26 23:17:30	3765	3599	166	4.4%
HD053443N053939V01	2015-01-28 19:30:00	3618	3522	96	2.6%
GAC094N39M1	2015-02-23 20:20:06	3736	3638	98	2.5%
HD103827N055449B02	2015-03-25 21:17:17	3677	3536	141	3.8%
HD145035N124702V01	2015-05-26 21:32:15	3492	3366	126	3.6%

NOTES:

This sample was selected from survey covering from 2014/12 to 2015/05.

where  $l \in [0, 4.5]$  is the distance change of objects  $x$  and  $y$ ,  $r$  is the radius 4.5 mm. Then the average area of  $S_{xy}$  is  $19.6539 \text{ mm}^2$  and the ratio of the possible collision zone in the fiber focal plane is  $p_{S_{xy}}$ .

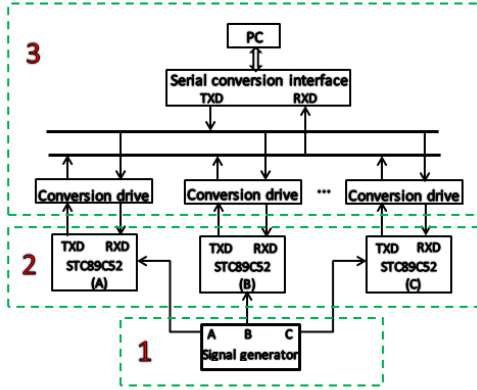
Generally, the total collision probability of any pair of fiber positioning units is defined as Eq. 5.

$$p = \sum_{j=2}^N C_N^j p_{S_o}^j (1 - p_{S_o})^{N-j} (1 - p_{S_{non}})^N p_{S_{xy} \dots j}, \quad (5)$$

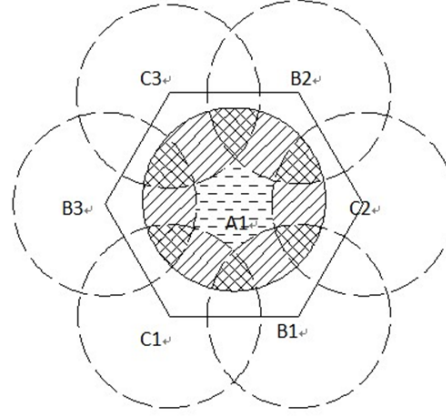
In fact,  $\sim 11630$  pairs of fiber-positioning units are located on the focal plane of LAMOST. We select several groups of input targets number and calculate the relevant collision probability for the radius of 4.5 mm and 6 mm respectively. Table 1 lists the result of  $p_{S_x}$ ,  $p_{S_{xy}}$ ,  $n_{S_x}$ ,  $n_{S_{xy}}$  and  $\Sigma(n_{S_x}, n_{S_{xy}})$ . It suggests that the lost objects number tends to be the maximum when the input targets number of the FoV is about 3500. The amount of the lost targets reaches a hundred, therefore it is necessary to retrieve the lost targets considering the designation of LAMOST survey.

## 2.2 Discussion

The collision probability reflects that the collision loss rate may reach about 3%. While the average failed



**Fig. 5** The collision frame of hardware processing system. The label ‘1’, ‘2’ and ‘3’ are a signal generation part, collision handling part and controlling system, respectively.



**Fig. 6** Three types of collision signal schematic drawing.

randomly selected from LAMOST observation results covering from 2014/12 to 2015/05. We infer that this loss rate difference may be induced by some other reasons. For example, some targets positioned by the fibers which are labeled as ‘abnormal’ will be missed in the observation. The label ‘abnormal’ means that these fibers have failed in locating for several positioning processes. The step motors for the fiber positioning units may miss some steps during LAMOST survey. Additionally, we do not exclude some operation mistakes.

Nevertheless, the lost objects number caused by the fiber units collisions reaches the level of 50 in every plate during the observations. It can bring down the efficiency of LAMOST to some extent. However, as many objects as possible should be observed since one of LAMOST scientific goals is to study the structure and the evolution of the Galaxy. It is valuable to retrieve these lost targets in the input catalogues. Handling the collisions between the fiber positioning units is very necessary. We design a hardware system to handle these situations during the observation stage, which will be described in the next section.

### 3 HANDLING COLLISION SYSTEM

#### 3.1 The Structure of the Hardware System

This hardware structure of the handling system is designed based on two programs which were built by the method of the voltage change inspection (Yan et al., 2007) and pulse contrast (Yan et al., 2008). And it has been simulated successfully for one fiber positioning unit by the proteus, which is introduced in our series paper (Liu & Wang, 2014). The hardware circuit structure of the handling collision includes three parts as shown in Fig. 5.

The first is the signal generation part which is designed for detecting the collisions between the fiber positioning units labeled as ‘1’. In this part we choose the MSC51 series SCM as the signal controller. The

result based on the detection signal. The last part labeled as '3' is the microcomputer controlling system. In this system, a method based on VB and RS-232 serial interface(Zhao et al., 2006) is utilized during the communications.

### 3.2 The Designation of the Simulation Experiment

#### I. Detection of Collisions Signal

This part aims to detect the collisions and send the result to part '2'. The detection of collisions signal is based on the pulse superposition. To detect this superposition come from different fiber units, we should assign different pulses to the 4000 fiber units, theoretically. Because of the relative position of the adjacent fiber units, the overlapped region includes three units at most as seen in Fig.6. Therefore, we assign three types of pulses (A, B, C), which have the same frequency and different phases, as the detection signals for the 4000 fiber positioning units. This designation can assure any adjacent fiber signals are different.

The frequency of fiber units stepping motors is 510  $Hz$ . To detect the collisions in real time, we apply a 200 $\mu s$  delay procedure by the MCU to generate the collision signals. When the collisions occur, the collision signals have multiple pulses in the same period. We choose the single chip STC89C52 as the core unit of pulse signal generator through the combination of the hardware circuit and software program phase. Therefore the frequency and amplitude of the waveform can change discretionarily in a certain range.

In the designation, firstly we set 1ms timer interrupt using the timer1 of STC89S52 chip as the time period of counting the collision pulses. Secondly during this period we count the collision pulses using counter0 of the chip. Thirdly when the timer1 interrupt occurs, if the value of the counter0 is 5, it suggests there is no collision. As a contrast, if the value is about between 10 and 15, we believe the fiber unit collisions with one or two adjacent units.

#### II. Signal processing

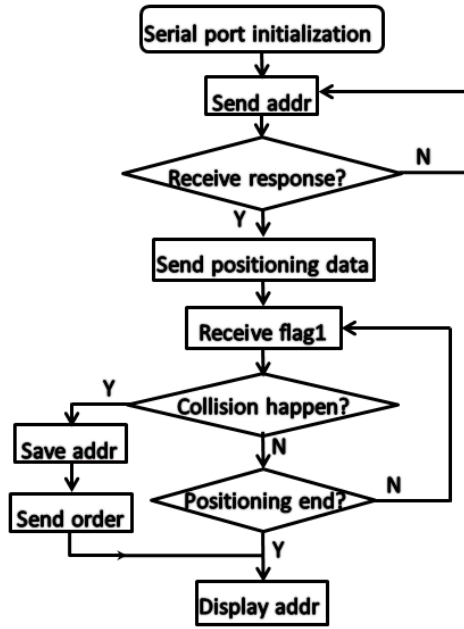
This part describes how to process detection signals. It includes the host controller and the slave controllers. The host controller is to receive the information from the MCU and convey commands to the sub-controller (MCU). The main steps are detailed as follows.

When the subsystem based on MCU sends the collision results to microcomputer through the serial bus, the main program on microcomputer receives the results and determines actual position of the fiber units timely. As a result, microcomputer can timely detect the fiber position units survey situation just through the data received from sub-controller. The Fig. 7 and Fig. 8 explain the procedure of the serial data communication including serial data reception and transmission.

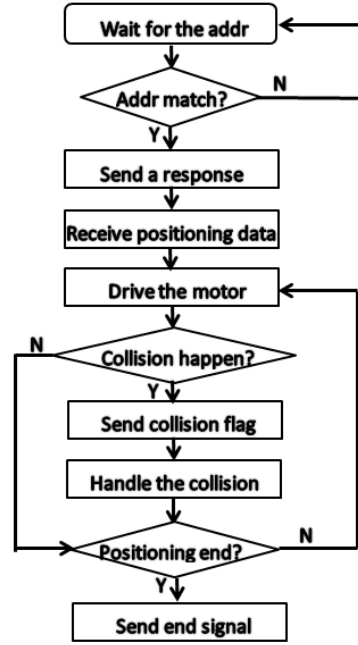
The sub-controllers implement two functions. One is to receive the collision results and transfer them to microcomputer controlling system, the other is to execute the instructions from microcomputer. STC89C52 MCU produced by company ATMEL (Liu et al., 2012) is used to control the positive inversion of stepping motor. The collision results will be sent to microcomputer by MScmm. The MCU will control the rotation way of units stepping motors when the instructions coming(Liu & Wang, 2014).

#### III. Serial communication

The serial communication between microcomputer and single chips plays a key role in achieving the above



**Fig. 7** The main controller of the collision handling system for LAMOST fiber positioning units process. The major function is sending the order to sub-controller and getting the situation of units.



**Fig. 8** The sub-controller of the collision handling system for LAMOST fiber positioning units process. The program includes receiving and feeding back the information of controlling units from the main controller.

the fiber unit motors steps and returns collision event information automatically. The whole hardware circuit consists of the slave MCUs which are considered as the second level systems and microcomputer. The MCU serial communication at a TTL level remains between 0 V and 5 V, while the microcomputer serial communication stands for the RS-232 standard. The most feasible solution to connect these two serial ports is just plugging a MAX-232 between them as the serial conversing interface(Ege et al., 2013). Thus, the steps of unit motor rotating are calculated by microcomputer according to the position of the objects and transmitted through the serial bus(Tian et al., 2007), which connects the microcomputer with the sub-controller. During the implement, one or two standard serial ports (COM1 or COM2), aims at achieving serial data communication through VB(Visual Basic) programming.

### 3.3 The Result Analysis

These three modules run orderly according to the modules function. When the collisions occur between the adjacent fiber positioning units during the observation, the hardware system is effective to handle this situation. The signal generator can be counted by the sub-controller without AD converter, and it also has the advantages of small volume, low price, stable performance and complete function. The serial communication method has characteristics of simple connection, high reliability, low cost, etc. This simulated

sub - controller MCU should be changed with FPGA which has high integration character. So one chip of FPGA can control more fiber units.

#### 4 SUMMARY

In this work, we first analyze the collision probability between fiber positioning units. To get this probability, we assume that the allocation of the targets in the focal plan is uniform, so it obeys the binomial distribution. Table 1 shows two boundaries under the radius of  $S_x$   $r = 4.5\text{ mm}$  and  $r = 6\text{ mm}$ . In fact, the most possible collision may happen at the radius  $5\text{ mm}$  (between  $4.5\text{ mm}$  and  $6\text{ mm}$ ) of  $S_x$ . If we choose the radius as  $5\text{ mm}$ , so the possible collision number of the fiber units will be about 67 when the number of the targets allocated in the focal surface is about 3500. It is worthy of finding a way to handle these fiber units collisions. We developed a new real-time hardware handling collision system for LAMOST fiber positioning units. It is a master - slave control system. In the designation we use microcomputer as our host controller which sends the position data and the collisions handling commands to the sub - controllers. The STC89C52 single - chip computer is used as slave controller which receives the host controller located commands and accepts the data from feedback.

Through this system, the broken fiber units could be marked accurately and changed efficiently. Additionally, it can improve the efficiency of LAMOST fiber units and the completeness of the survey. Because LAMOST has been operated for several years, some fiber units should be repaired or replaced at regular intervals. To a certain extent, the hardware system may also lengthen the service time of the fiber units. It is a complex system for handling 4000 fiber units, further research is required in the future.

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